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Research Article

Mechanical Properties of Fast-Growing Poplar Reinforced with Carbon Fiber

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This paper presents mechanical properties of fast-growing poplar specimens reinforced with carbon fibers. A total of 90 specimens including 10 contrast specimens were tested to investigate the influence from the following parameters: (a) different carbon fiber ratios (0.167%, 0.251%, 0.334%, 0.401%, and 0.501%) and (b) different fiber locations. The failure mode, compressive strength, elastic modulus, and axial deformation of specimens were analyzed. The test results indicate the following: (1) The compressive strength, elastic modulus, and axial deformation of specimens reinforced with carbon fiber were significantly improved compared with that of fast-growing poplar specimens. The compressive strength, elastic modulus, and axial deformation increased by 54.1–76.03%, 11.58–22.89%, and 24.86–60.06%, respectively. (2) There was little effect on the compressive strength of the specimen with the increase of carbon fiber ratio. With the increase of carbon fiber ratio, the elastic modulus of specimens slightly decreased and the axial deformation increased. The elastic modulus decreased by 1.39–18.69%, and the axial deformation increased by 10%–48%. (3) The different locations of the carbon fiber distribution resulted in a large difference in the compressive strength of the specimens, while the effects on the modulus of elasticity and axial deformation were not significant. Finally, the compressive strength calculation formula was proposed.

1. Introduction

Timber structure is a popular structural form in various regions of the world for its seismic resistance and heat preservation [1]. The wood materials are in short supply because of policies of closing mountains for afforestation and no cutting. Fast-growing poplar is widely planted for its high survival rate and short growth period [2–4]. However, the application of fast-growing poplar is limited in the field of building for the loose texture and low strength. Improving the mechanical properties of rapid growth materials has become the focus of attention. The method of gluing fast-growing poplar reinforced with carbon fiber was used in this paper.

In recent years, the scholars have done a lot of work on the mechanical properties of fast-growing poplar, it is mainly focusing on chemical modification, glued wood, and glued fast-growing poplar reinforced with carbon fiber [5–24]. The main research results in chemical modification are as follows: Yue et al. [5, 6] studied the influence of boric acid phenolic formaldehyde resin (BPF) impregnation on the mechanical and combustion properties of fast-growing poplar timber specimens. The results showed that the strength of modified poplar timber specimens increased by 11.2–45.8% with the increase of BPF impregnation concentration. Pure lactic acid oligomers (OLA) and phenolic methylol urea were also commonly used in chemical impregnation [7–9]. The internal reactive deposition of $CaCl_2$ and $NaCO_3$ was used in modification studies [10], and some studies even combined heat treatment, chemical impregnation, and other methods to improve the performance of poplar [11, 12]. Liu et al. [13] conducted bending tests on 31 laminated timber beam specimens, and the test results showed that the combination mode and size of laminates have significant influence on the mechanical properties of specimens.

With the deepening of the research on the modification of fast-growing poplar, it has been widely used that pasting or winding carbon fiber to improve mechanical properties [14–23]. Zuo et al. [14] studied the flexural performance of modified flax fiber reinforced glued laminated timber beams. The results showed that the flexural load capacity and flexural stiffness of glued laminated timber beam increased with the number of FFRP layers applied at the bottom. He et al. [15, 16] studied the mechanical properties of modified reconstituted wood structures and revealed that the improvement of the strength, modulus of elasticity, and strength-to-weight ratio of the reconstituted wood material, which effectively strengthened the interaction between the reconstituted wood beam, the reconstituted wood column, the bolts, and the steel infill plate, and the nodal force performance was significantly improved. Juliano Fiorelli et al. [17] studied the method used to produce glulam beams led to a higher efficiency of the structural elements. Zheng [18] used carbon fiber to wind the whole specimens, in order to improve its compressive bearing capacity. The compressive bearing capacity increased by 21.4% after first layer had been wound, and 83.1% after third layer had been wound. José Sena-Cruz [24] studied the bonding behavior between integrated material and GFRP by pull-out test. The stress-slip relationship for the local bonding was obtained by test data. A significant increase in flexural load capacity was found for reinforced, prestressed, and prestressed reinforced beams [25]. In addition, Wei et al. [26–29] conducted experimental research and simulation analysis on the mechanical properties of bamboo. It was found that the residual plastic strain ratio of bamboo scrimber was far lower than that of concrete, and new composite materials such as recombinant bamboo and steel-reinforced bamboo scrimber were proposed. This literature provides important insights into the study of mechanical properties of fast-growing poplar reinforced with carbon fiber.

The previous research on improvement methods of fast-growing poplar mainly focuses on chemical impregnation, physical compaction, or carbon fiber reinforcement. The chemical impregnation and physical compaction methods can improve the mechanical properties of fast-growing poplar; however, this method has little improvement. The carbon fiber was added between timber boards in this paper to form a new composite material, which can be better applied in the building field. Considering the influence of different carbon fiber ratio and different fiber location, the fast-growing poplar reinforced with carbon fiber was tested and the influence rule of mechanical properties of fast-growing poplar reinforced with carbon fiber was obtained.

2. Experimental Program

2.1. Design of Specimens. A total of 90 fast-growing poplar specimens were designed and tested, as shown in Table 1 and Figures 1–3. These included 10 comparison specimens and 80 specimens reinforced with carbon fiber, which are 100 mm × 100 mm × 100 mm cubes. Ten pieces of 10 mm × 100 mm × 100 mm timber boards were spliced together to form one specimen using structural adhesive. All the specimens were made in accordance with the code for design of timber structure [30].

In the production process, the fast-growing poplar lumber was cut, dried, cleaned, polished, and flattened to form the fast-growing poplar laminate. Carbon fiber cloth was cut into 100 mm × 100 mm size. All materials were bonded together by evenly brushing structural adhesive, as shown in Figure 1. The structural adhesive was made by mixing epoxy resin and curing agent in the ratio of 2:1. The finished specimens were cured and maintained under 0.4 MPa pressure for 48 hours.

2.2. Materials. The specimens were made of No. 108 artificially cultivated fast-growing poplar (diameter at a breast height of about 20 cm, tree height of about 9 m, no insect pests and other tree quality defects, and straight trunk), which is mainly produced in Jinan city, Shandong Province, China. The 0.167 mm thick (300 g) carbon fiber was used in the test. The main components of the structural adhesive were epoxy resin and curing agent (mainly phenol-4-sulfonic acid) at the ratio of 2:1, the density of structural adhesive is 2000 kg/m^3, and the structural adhesive between layers is 2000 g/m^2.

2.3. Moisture Content. The moisture content has a significant impact on the compression strength of the composite material. Ten cubic test blocks of 20 mm × 20 mm × 20 mm were made and measured according to Method for Determination of the Moisture Content of Timber GB/T 1931–2009 [31]. The average moisture content of the fast-growing poplar was 12.39%, which met the requirements of code GB/T 50708–2012 [32], as can be seen in Table 2.

3. Experimental Process

The test was carried out using a WAW-1000C universal testing machine (maximum test force 1000 KN) for loading in the vertical axis. The specimens reinforced with carbon fiber were placed in the testing machine, and geometric axis alignment was performed according to the standard for test method of timber structures. The test was loaded at a rate of 2 mm/min until the specimen cannot withstand the load and the test was terminated [33].

4. Experimental Results and Discussion

4.1. Failure Mode. The failure mode of *Y*1 was that all specimens had horizontal cracks, and some specimens had vertical cracks. From the observation of the failure

Table 1: Design parameters of the specimens.

Specimen		Carbon fiber position	Carbon fiber ratio R (%)
Comparison	$Y1$	--	--
	$X1$	--	--
Carbon fiber ratio	$A1$	2-3, 5-6, 8-9	0.167
	$A2$	2-3, 5-6, 8-9	0.251
	$A3$	2-3, 5-6, 8-9	0.334
	$A4$	2-3, 5-6, 8-9	0.401
	$A5$	2-3, 5-6, 8-9	0.501
Carbon fiber position	$B1$	1-2, 5-6, 9-10	0.501
	$B2$	1-2, 2-3, 5-6, 8-9, 9-10	0.501

Note. $R = \frac{V_{\text{carbon fibre}}}{V_{\text{specimen}}} \times 100\%$, R is the carbon fiber ratio, which is the ratio of the volume of the carbon fiber to the volume of the reinforced specimen; V_c is the volume of the carbon fiber; V_s is the volume of the specimen.

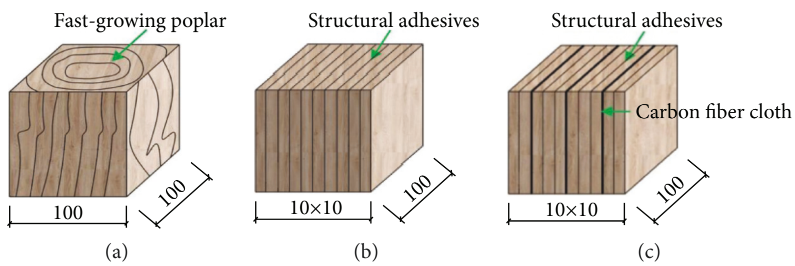

Figure 1: Layout of the specimens: (a) $Y1$, (b) $X1$, and (c) $A1$-5 and $B1$-2.

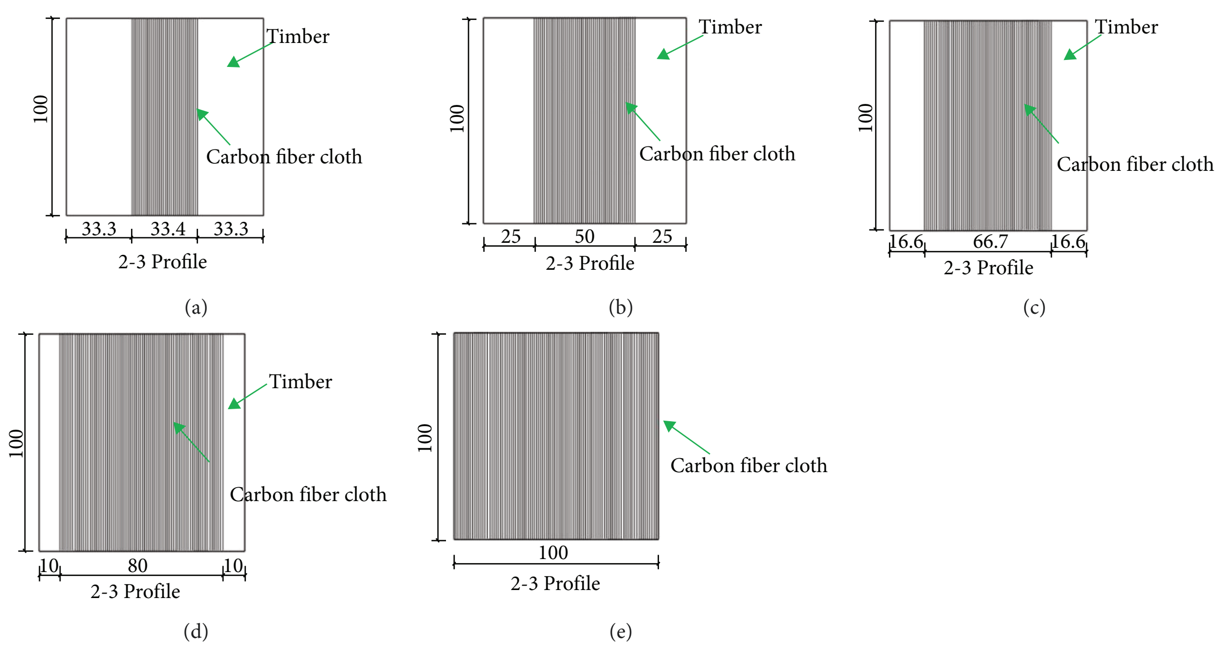

Figure 2: Different carbon fiber ratios: (a) $A1$, (b) $A2$, (c) $A3$, (d) $A4$, and (e) $A5$.

specimens, it can be seen that the wood fiber was severely squeezed, and the specimen showed obvious compression deformation. The specific phenomenon is shown in Figure 4.

The failure modes of specimens reinforced with carbon fiber are similar to that of fast-growing poplar specimens, as shown in Figure 5. Most specimens only appeared horizontal cracks, and some specimens simultaneously appeared horizontal cracks and a few vertical cracks. Compared with specimen $Y1$, horizontal cracks of specimens $A1$ to $A5$ were randomly distributed and had no continuity. The vertical cracks were mostly distributed in the adhesive location. With the carbon fiber ratio increases, the deformation of the specimen becomes greater and its damage reaches earlier. The outermost laminates of specimens $A4$ and $A5$ separated from the specimens, forming isolated laminates, and the continued loading of the test caused the outer laminates to buckle, and the test was ended.

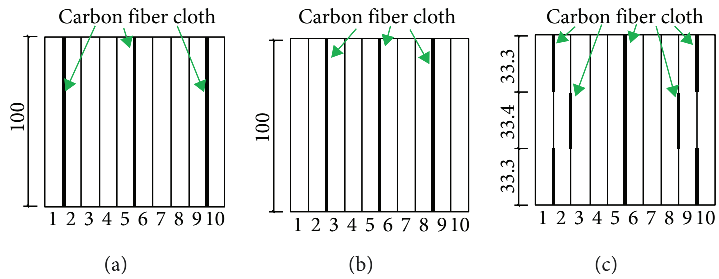

Figure 3: Different carbon fiber positions: (a) $A5$, (b) $B1$, and (c) $B2$.

Table 2: Moisture content test data.

Number	1	2	3	4	5	Average %
Moisture content %	11.56	11.96	12.27	12.53	13.14	
Number	6	7	8	9	10	12.39
Moisture content %	12.73	12.13	12.40	12.72	12.43	

Figure 4: Failure mode of the specimen $Y1$.

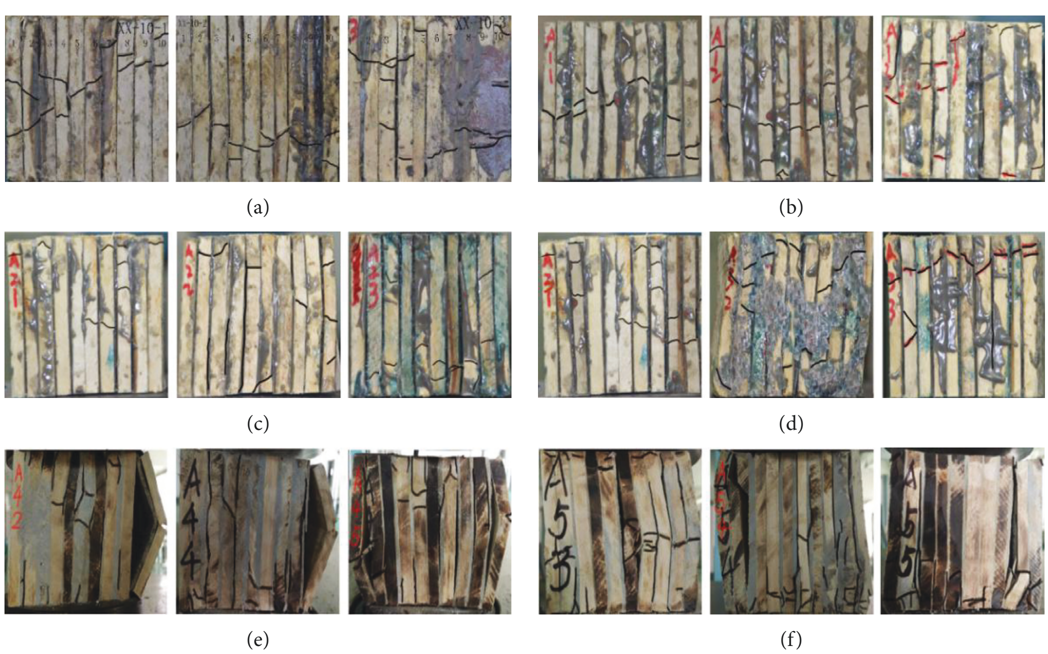

Figure 5: Failure mode of the specimens $X1$ and $A1$-5: (a) $X1$, (b) $A1$, (c) $A2$, (d) $A3$, (e) $A4$, and (f) $A5$.

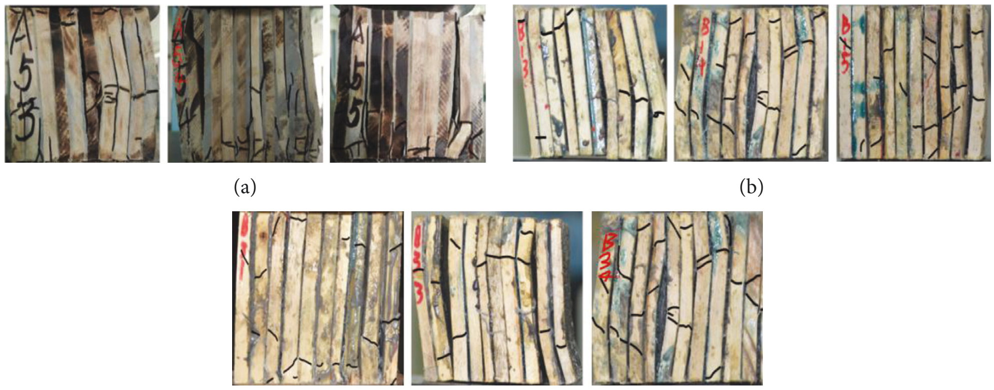

Figure 6: Failure mode of the specimens (a) $A5$, (b) $B1$, and (c) $B2$.

Table 3: Mechanical parameters of specimens with different carbon fiber ratios.

Specimen	f_a (MPa)	S (standard deviation)	f_k (MPa)	α_3	E_a (MPa)	Δ_a (mm)
$Y1$	22.84	2.593	17.38	—	1320	3.58
$X1$	27.74	1.509	24.56	1	1586	4.24
$A1$	35.69	3.27	28.81	1.1730	1564	4.47
$A2$	35.31	2.239	30.60	1.2459	1622	4.61
$A3$	34.42	2.767	28.60	1.1645	1508	4.80
$A4$	33.24	3.068	26.78	1.0904	1473	5.05
$A5$	31.59	2.15	27.07	1.1022	1291	5.73

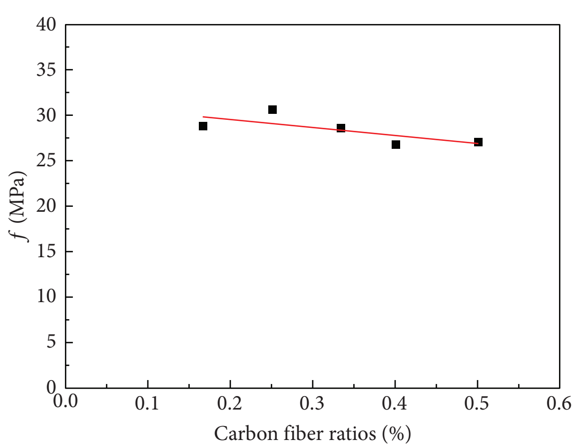

Figure 7: Compressive strength of specimens with different carbon fiber ratios.

According to the experimental phenomena, the carbon fiber positions of specimens $A5$, $B1$, and $B2$ were different, but their failure modes were similar, as shown in Figure 6. At the early stage of loading, specimens $A5$, $B1$, and $B2$ produced a slight wood extrusion sound. With the increase of load, the specimens showed obvious bending deformation and cracked seriously between some boards. The bond force was lost, some boards were separated from each other, and the outer boards of some specimens were even broken, and the test was ended.

4.2. Compressive Strength. The following data are taken from the data collection of the test machine, and the average of the 10 specimens is taken as the selected value, where f_a is average compressive strength of 10 specimens, S is standard deviation, f_k is standard value of compressive strength, and α_3 is the improvement coefficient. E_a is the average of elastic modulus of 10 specimens, and Δ_a is the average axial deformation of 10 specimens. Where f_k was collated according to GB 50005–2017 [30] and E_a and Δ_a were collated according to GB/T 50329–2012 [33], we have the results in Table 3 and Figures 7, 8, and 9.

Table 3 and Figure 7 show that the compressive strength of specimens $A1$ to $A5$ is significantly improved in comparison with that of specimens $Y1$ and $X1$. Compared with that of specimen $Y1$, the compressive strength of the specimens increased by 54.1–76.03%. Compared with that of specimen $X1$, the compressive strength of the specimens increased by 9.04–24.56%. The reason is that carbon fiber is a high strength and high modulus fiber, which increases the resistance of the specimen to bending deformation and therefore increases the compressive strength of the specimen. In addition, with the carbon fiber ratio increases, the effect on the compressive strength of the specimens is not significant. According to the above test data, the compressive strength formula of specimens with different carbon fiber ratio was obtained by fitting, as shown in the following equation:

$$y = (-0.4992x + 1.798)f_0, \quad (1)$$

where y is the measured compressive strength of carbon fiber specimen, x is the carbon fiber ratio, and f_0 is the compressive strength of fast-growing poplar specimen.

As shown in Table 3, the compressive strength of specimens $A1$ to $A5$ with different fiber proportion increased

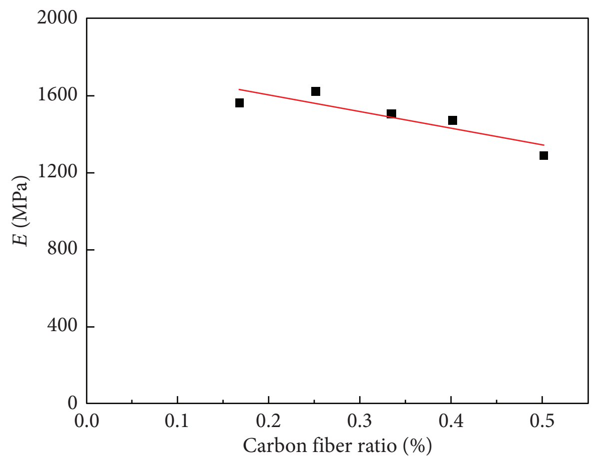

FIGURE 8: Elastic modulus of specimens with different carbon fiber ratios.

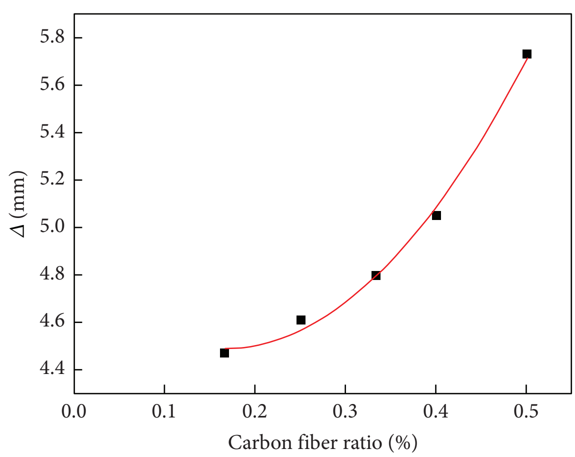

FIGURE 9: Axial deformation of specimens with different carbon fiber ratios.

by 17.3%, 24.6%, 16.4%, 9.0%, and 10.2%, respectively, compared with that of $X1$. Through data fitting, the calculation formula of α_3 was obtained, as shown in the following equation:

$$\alpha_3 = -0.3532\rho_c + 1.2721. \quad (2)$$

4.3. Elastic Modulus. It can be seen from Table 3 and Figure 8 that the elastic modulus of specimens $A1$ to $A5$ is improved in comparison with that of specimens $Y1$. Compared with that of specimen $Y1$, the elastic modulus of the specimens increased by 11.58–22.89%. Compared with that of specimen $X1$, the elastic modulus of the specimens decreased by 1.39–18.57%. The elastic modulus of specimens decreased in the range of 3.56–21.11% with the increase of carbon fiber ratio. As can be seen from the above research, when the ratio of carbon fibers increases, the area of the carbon fibers increases. The bond between the carbon fibers and the structural adhesive is less than the bond between the wood and the structural adhesive. The load-bearing capacity of the specimen depends on the adhesion between carbon fiber and structural adhesive. It leads to a reduction in the modulus of elasticity of the specimen. According to the above test data, the elastic modulus formula of specimens with different carbon fiber ratio was obtained by fitting, as shown in the following equation:

$$y = (-0.673x + 1.413)E_0, \quad (3)$$

where y is the measured elastic modulus of carbon fiber specimen, x is the carbon fiber ratio, and E_0 is the elastic modulus of fast-growing poplar specimen.

TABLE 4: Mechanical parameters of specimens with different fiber position.

Specimen	f_a (MPa)	S (standard deviation)	f_k (MPa)	E_a (MPa)	Δ_a (mm)
A5	31.59	2.15	27.07	1291	5.73
B1	30.46	4.79	20.38	1351	5.58
B2	31.62	1.62	28.21	1428	6.25

4.4. Axial Deformation. Table 3 and Figure 9 show that the axial deformation of specimens A1 to A5 is significantly improved in comparison with that of specimens Y1 and X1. Compared with that of specimen Y1, the axial deformation of the specimens increased by 24.86–60.06%. Compared with that of specimen X1, the axial deformation of the specimens increased by 5.42–35.14%. When the carbon fiber ratio increased, the axial deformation increased, with a maximum increase of 48%. According to the above test data, the axial deformation formula of specimens with different carbon fiber ratio was obtained by fitting, as shown in

$$y = \left(3.05x^2 - 1.02x + 1.34\right)\Delta_0, \quad (4)$$

where y is the axial deformation of carbon fiber specimen, x is the carbon fiber ratio, and Δ_0 is the axial deformation of fast-growing poplar specimen.

4.5. Compressive Strength, Elastic Modulus, and Axial Deformation of Carbon Fiber Position. It can be seen from Table 4 and Figure 10 that the changing position of the carbon fibers has an effect on the compressive strength, but it has little effect on the modulus of elasticity and axial deformation. The maximum difference of compressive strength, elastic modulus, and axial deformation between specimens B1 and B2 and the comparison specimen A5 was 24.7%, 10.60%, and 9.1%, respectively.

5. Calculation of Compressive Strength

Although the specimens reinforced with carbon fiber were made of poplar timber, structural adhesive, and carbon fiber, the compressive strength was mainly provided by adhesive and timber. Carbon fiber itself has not compressive strength, but it can improve the ability of specimen to resist bending deformation, thus affecting the compressive strength of specimen. Therefore, the influence of carbon fiber on the

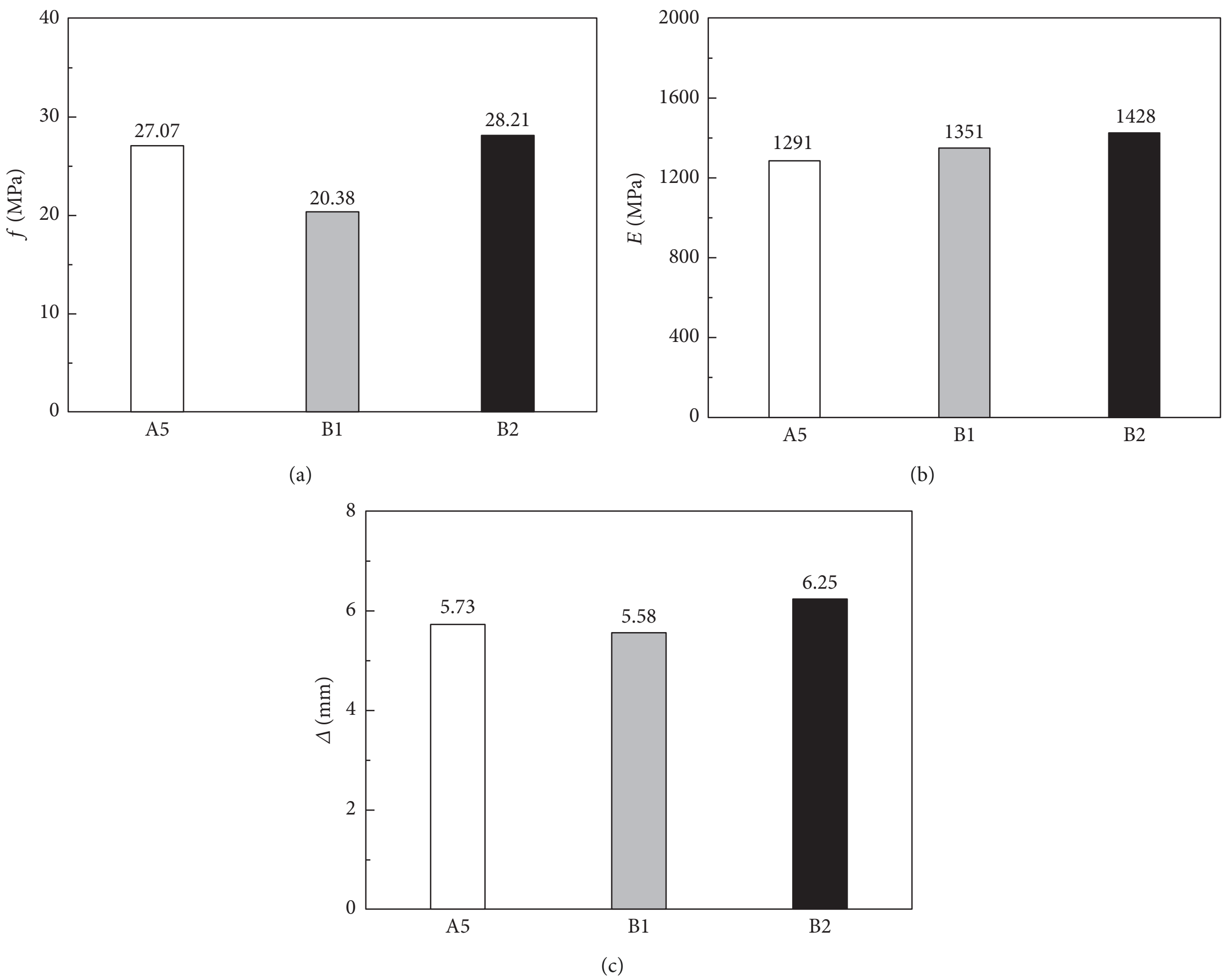

Figure 10: (a) Compressive strength, (b) elastic modulus, and (c) axial deformation of specimens with different carbon fiber positions.

Table 5: Value of α_1 and α_2.

	(5) + (6)	(5) + (7)	(5) + (8)	(6) + (7)	(6) + (8)	(7) + (8)	Average
α_1	0.742	0.583	0.714	0.416	0.702	0.894	0.675
α_2	1.245	1.463	1.283	2.190	1.361	0.113	1.276

strength of reinforced specimens was expressed by the improvement coefficient; that is, the compressive strength formula of fast-growing poplar specimens reinforced with carbon fiber could be expressed by the following equation:

$$f_c = \alpha_3 \left(\alpha_1 \rho_w f_w + \alpha_2 \rho_a f_a \right), \quad (5)$$

where f_c is the compressive strength of carbon fiber reinforced fast-growing poplar, f_w is the compressive strength of timber, f_a is the compressive strength of adhesive, ρ_w is the timber content $\rho_w = 100 \times t_w/99 \times t_w + 100$, $\rho_a$is the adhesive content $\rho_a = 100 - t_w/99 \times t_w + 100$, t_w is the thickness of the timber, α_1 is the combination coefficient of timber compressive strength, and α_2 is the combination coefficient of structural adhesive strength.

In Eq (5), specimen X1 did not consider the effect of carbon fibers on the compressive strength, so the coefficient α_3 is taken as 1 ($\alpha_3 = 1$). The compressive strength of the reinforced fast-growing poplar with the thickness of 5 mm, 10 mm (X1), 15 mm, and 20 mm were obtained from [34]. The test result of compressive strength was substituted into equation (5) to give equation (6). The values of α_1 and α_2 could be obtained by solving any pair of equations selected from equation (6). The average values of α_1 and α_2 were 0.675 and 1.276, respectively, as shown in Table 5.

$$\begin{cases} \alpha_1 \times 0.8403 \times 22.84 + \alpha_2 \times 0.1597 \times 87.6 = 31.66, \\ \alpha_1 \times 0.9174 \times 22.84 + \alpha_2 \times 0.0826 \times 87.6 = 24.56, \\ \alpha_1 \times 0.9434 \times 22.84 + \alpha_2 \times 0.0566 \times 87.6 = 19.82, \\ \alpha_1 \times 0.9615 \times 22.84 + \alpha_2 \times 0.0385 \times 87.6 = 20.01. \end{cases} \quad (6)$$

Equation (2) was substituted into equation (5) to give equation (7) for calculating the compressive strength of specimens reinforced with carbon fiber.

Here, ρ_c is the carbon fiber ratio.

$$f_c = \alpha_3 (\alpha_1 \rho_0 f_0 + \alpha_2 \rho_a f_a) = (-0.3532\rho_c + 1.2721)(0.675\rho_w f_w + 1.276\rho_a f_a). \tag{7}$$

6. Conclusion

This paper experimentally and analytically investigated mechanical properties of fast-growing poplar reinforced with carbon fiber. The following conclusions can be drawn:

(1) The compressive strength, elastic modulus, and axial deformation of specimens reinforced with carbon fiber are significantly improved compared with those of fast-growing poplar specimens. The compressive strength, elastic modulus, and axial deformation increase by 54.1–76.03%, 11.58–22.89%, and 24.86–60.06%, respectively.

(2) With the increase of carbon fiber ratio, the range of variation in compressive strength is insignificant, the elastic modulus of specimens slightly decreases, and the axial deformation increases. The elastic modulus decreases by 1.39–18.69%, and the axial deformation increases by 10%–48%.

(3) The different locations of the carbon fiber distribution resulted in a large difference in the compressive strength of the specimens, and the maximum difference of compressive strength is 8 MPa, while the effects on the modulus of elasticity and axial deformation are not significant.

(4) The compressive strength calculation formula of specimens reinforced with carbon fiber is established.

Data Availability

The numerical and measurement data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] I. Smith and M. A. Snow, "Timber: an ancient construction material with a bright future," *The Forestry Chronicle*, vol. 84, no. 4, pp. 504–510, 2008.

[2] T. Johansson and A. Karačić, "Increment and biomass in hybrid poplar and some practical implications," *Biomass and Bioenergy*, vol. 35, no. 5, pp. 1925–1934, 2011.

[3] W.-j. Liang, H.-q. Hu, F.-j. Liu, and D.-m. Zhang, "Research advance of biomass and carbon storage of poplar in China," *Journal of Forestry Research*, vol. 17, no. 1, pp. 75–79, 2006.

[4] Z. Sun, Y. Zhang, and e tal, "Research status and prospect of organic-inorganic compound modified fast-growing wood," *Materials Reports*, vol. 35, no. 05, pp. 5181–5187, 2021.

[5] K. Yue, X. C. Cheng, and L. L. Wan, "Effect of modification on mechanical property and fire-retardant behavior of fast-growing poplar timber," *Journal of Combustion Science and Technology*, vol. 22, no. 5, pp. 426–432, 2016.

[6] K. Yue, Z. Chen, W. Lu et al., "Evaluating the mechanical and fire-resistance properties of modified fast-growing Chinese fir timber with boric-phenol-formaldehyde resin," *Construction and Building Materials*, vol. 154, pp. 956–962, 2017.

[7] G. Charlotte, N. Marion, F. T. Marie, R. Lauri, and G. Philippe, "Influence of water and humidity on wood modification with lactic acid," *Journal of Renewable Materials*, vol. 6, no. 3, pp. 259–269, 2018.

[8] H. Chen, X. Miao, Z. Feng, and J. Pu, "In situ polymerization of phenolic Methylolurea in cell wall and induction of pulse-pressure impregnation on green wood," *Industrial & Engineering Chemistry Research*, vol. 53, no. 23, pp. 9721–9727, 2014.

[9] F. Cheng, Y. Hu, and L. Li, "Interfacial properties of glass fiber/unsaturated polyester resin/poplar wood composites prepared with the prepreg/press process," *Fibers and Polymers*, vol. 16, no. 4, pp. 911–917, 2015.

[10] C. Qian, *Study on the Preparation and Properties of poplar Modified by Internal Reaction Deposition*, Nanjing Forestry University, China, 2020.

[11] Y. Dong, Y. Yan, Y. Zhang, S. Zhang, and J. Li, "Combined treatment for conversion of fast-growing poplar wood to magnetic wood with high dimensional stability," *Wood Science and Technology*, vol. 50, no. 3, pp. 503–517, 2016.

[12] W. D. Li, C. Wang, Y. Zhang, C. Jia, C. C. Gao, and J. W. Jin, "The influence of hot compression on the surface characteristics of poplar veneer," *Bioresources*, vol. 9, no. 2, pp. 2808–2823, 2014.

[13] W. Q. Liu and H. F. Yang, "Experimental study on flexural behavior of engineered timber beams," *Journal of Building Structures*, vol. 29, no. 1, pp. 90–95https, 2008.

[14] H. Zuo, Z. Wang, and Y. Li, "Flexural behavior of modified flax fiber reinforced polymer reinforced glulam beams," *Journal of Northeast Forestry University*, vol. 49, no. 4, pp. 76–80, 2021.

[15] M. He, Li Zheng, and L. Wu, "Study on mechanical properties and strength design index of modified reconstituted wood," *Journal of Building Structures*, vol. 41, no. S1, pp. 364–372, 2020.

[16] M. He, duo Tao, Li Zheng, and J. Zhang, "Experimental investigation of mechanical property of dowel-type post-and-beam connections made of wood scrimber composite," *Journal of Southeast University (Natural Science Edition)*, vol. 48, no. 06, pp. 1013–1020https, 2018.

[17] J. Fiorelli and A. A. Dias, "Glulam beams reinforced with FRP externally-bonded: theoretical and experimental evaluation," *Materials and Structures*, vol. 44, no. 8, pp. 1431–1440, 2011.

[18] Y. L. Zheng, Q. F. Wang, and Y. H. Huang, "Experimental study on axial compressive behaviors of timber column strengthened with GFRP," *Journal of Huaqiao University*, vol. 33, no. 3, pp. 321–324, 2012.

[19] Y. H. Guo, Y. B. Lin, and B. Na, "Evaluation of physical and mechanical properties of fiber-reinforced poplar scrimber," *Bioresources*, vol. 12, no. 1, pp. 43–55, 2017.
[20] P. X. Wei, J. H. Brad, and D. G. Wang, "Mechanical properties of poplar laminated veneer lumber modified by carbon fiber reinforced polymer," *Bioresources*, vol. 8, no. 4, pp. 4883–4898, 2013.
[21] S. Ahmad, J. Mohammad, T. H. S. Mohamed, and H. Azman, "Preliminary study on tensile and impact properties of kenaf/bamboo fiber reinforced epoxy composites," *Journal of Renewable Materials*, vol. 6, no. 5, pp. 529–535, 2018.
[22] S. H. Li, B. L. Gao, and G. Q. Li, "Experimental study on poplar LVL beams reinforced with CFRP sheets," *Journal of Building Structures*, vol. 39, no. 2, pp. 109–112, 2009.
[23] G. M. Raftery and A. M. Harte, "Low-grade glued laminated timber reinforced with FRP plate," *Composites Part B: Engineering*, vol. 42, no. 4, pp. 724–735, 2011.
[24] J. Sena-Cruz, J. Branco, M. Jorge, J. A. O. Barros, C. Silva, and V. M. C. F. Cunha, "Bond behavior between glulam and GFRP's by pullout tests," *Composites Part B: Engineering*, vol. 43, no. 3, pp. 1045–1055, 2012.
[25] H. Yang, D. Ju, W. Liu, and W. Lu, "Prestressed glulam beams reinforced with CFRP bars," *Construction and Building Materials*, vol. 109, no. 15, pp. 73–83, 2016.
[26] W. Yang, Si Chen, S. Tang, K. Zheng, and J. Wang, "Mechanical behavior of bamboo composite tubes under axial compression," *Construction and Building Materials*, vol. 245127681 pages, 2022.
[27] W. Yang, S. Tang, Ji Xuewei, K. Zhao, and G. Li, "Stress-strain behavior and model of bamboo scrimber under cyclic axial compression," *Engineering Structures*, vol. 209, no. 4, 110279 pages, 2020.
[28] Y. Wei, K. Zhao, C. Hang, S. Chen, and M. Ding, "Experimental study on the creep behavior of recombinant bamboo," *Journal of Renewable Materials*, vol. 8, no. 3, pp. 251–273, 2020.
[29] W. Yang, S. Yan, K. Zhao, F. Dong, and G. Li, "Experimental and theoretical investigation of steel-reinforced bamboo scrimber beams," *Engineering Structures*, vol. 223, no. 12, 111179 pages, 2020.
[30] "Ministry of housing and urban rural development of the people's Republic of China," in *GB50005-2017, Code for Design of Timber Structures*China Architecture & Building Press, Beijing , China, 2017.
[31] "Ministry of housing and urban rural development of the people's Republic of China," in *GB/T1931-2009, Method for Determination of the Moisture Content of Timber*China Architecture & Building Press, Beijing , China, 2009.
[32] "Ministry of housing and urban rural development of the people's Republic of China," in *GB/T50708- 2012, Technical Code of Glued Laminated Timber Structures*China Architecture & Building Press, Beijing , China, 2012.
[33] "Ministry of housing and urban rural development of the people's Republic of China," in *GB/T50329- 2012, Standard for Test Method of Timber Structures*China Architecture & Building Press, Beijing , China, 2012.
[34] Q. J. Liu, Y. Z. Wang, Y. Gao, B. J. Zhang, and B. Li, "The experimental study on mechanical behavior of modified fast-growing poplar," *Journal of Civil & Environmental Engineering*, vol. 41, no. 5, pp. 99–108, 2019.